63-4-1

Technical Documentary Report No. SSD-TDR-63-146

NEAR INFRARED BACKGROUND CLUTTER AND ATMOSPHERIC TRANSMISSION

by

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Semiannual Report under
Contract AF 04(695)-202
Task 447906
Project 4479
730F Technical Area
C-65207
May 1963

Prepared for

Space Systems Division
Air Force Systems Command
United States Air Force
Los Angeles, California

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I. INTRODUCTION

This report summarizes the instrumentation phase of an infrared background measurement program whose objective is to obtain infrared background data from a U-2 aircraft that will assist in the design and evaluation of future space-based infrared detection systems.

Specifically, it is planned to measure the statistics of background clutter in the 1-3 micron region with 0.10 micron resolution for a variety of geometrical conditions of solar illumination and viewing and to measure solar spectra for a range of aircraft altitudes and solar elevations. The background clutter measurements are intended to establish:

1. Spectral correlation in various spectral bands
2. Spatial correlation between radiation originating from different points in space in the azimuthal direction
3. The dependence of amplitude distributions of background radiance on wavelength, in radiation, viewing and scattering angles.

The solar spectra are intended to establish:

1. Correction factors for atmospheric attenuation as a function of altitude and slant path
2. The degree of homogeneity of the atmosphere above various altitudes.

This report, which covers the period from November 1962 to May 1963, deals with the instrumentation and data gathering aspects of the program. Detailed discussion of data analysis procedures, as well as background and solar radiance measurements, will be presented in a later report.

II. INSTRUMENT REQUIREMENTS

The basic requirements that must be met to obtain background clutter data and solar spectra will now be summarized.

The primary measuring instrument is a recording spectrometer operating in the 1-3 micron region with resolution of 0.10 micron. The line of sight of the spectrometer is to be directed to the side of the aircraft to permit viewing the background at nadir angles of either 45° or 80°. Scanning will be limited to that provided by the spectral scan rate and aircraft velocity.

The azimuthal width of the field of view will subtend 1.0 nautical mile on the ground for a nadir angle of 80° and an aircraft altitude of 65,000 ft. The angular width of the field of view in elevation will be three times the angle width in azimuth. The spectral scan rate will permit recording a complete spectrum in a period of time no longer than required for the aircraft to traverse one quarter of the field of view. The minimum scan rate will thus depend upon the aircraft velocity and azimuthal width of field of the field of view for 45° nadir viewing. One spectrum will be recorded for each spatial resolution element. The sensitivity of the system will permit sensing background radiance levels of 5×15^{6} watts/cm^{2} sterod micron with a signal-to-noise ratio of 1/1.

Solar spectra will be recorded in the same spectral region with the same spectral resolution for insolation angles ranging from 10° above the horizon to the zenith.

All radiometric data will be recorded on magnetic tape with capacity for recording 3000 spectra during a single flight. The form of data recording will permit direct conversion into digital computer format with standard equipment.

A time lapse camera will be bore sighted with the spectrometer and photographs will be obtained at 20 mile intervals along the flight path.

III. BASIC INSTRUMENTATION

The instrument package to be used for this program was originally developed under ARPA Contract (Nonr-3556(00)) for closely related measurements. In its original form the cloud spectrometer consisted of a Perkin-Elmer SG-4 rapid scan spectrometer together with optics that permit individual or sequential recording of the intensity and spectral distribution of radiation emitted by or reflected from clouds and the intensity of and spectral distribution of incident solar radiation. In addition, provision was made to record time lapse photographs of cloud systems or terrain under observation by the spectrometer by means of a time lapse movie camera bore sighted with the spectrometer, to obtain horizon-to-horizon photographs with a large tracker camera, to measure aircraft-sun orientation, pitch, roll, yaw, time, and aircraft heading, and to measure the potential gradient present above the clouds. The various data channels are either simultaneously recorded or photographed in such a manner that full correlation is insured.

The SG-4 is a compact Ebert spectrometer that can function under a wide range of operating conditions. Spectral scan is achieved by means of a dc motor, interchangeable gear trains, and electrically operated clutches which control direction of rotation. The scan rate is continuously variable from 1 to 300 seconds for full grating rotation or travel of 15°. The grating travel can also be varied from a fraction of a degree to full range and can be centered at any desired wavelength.

The spectrometer is equipped with Dall-Kirkham foreoptics with numerical aperture F/2.7. Order isolation is achieved by means of multilayer interference filters mounted on a rotatable filter wheel positioned immediately behind the exit slit. A wide choice of interchangeable, prefocused detectors can be employed. The instrument is now equipped with a 100 line/amm grating and cooled PbS, InSb, and p-type Au-Ge detectors, thus permitting operation in the 1 to 8 micron region.

Entrance and exit slits of fixed width were supplied with the instrument. The original design incorporated a solenoid-operated slit interchange permitting operation with either 0.01 or 0.10 micron resolution. The slit interchange did not prove to be mechanically stable and has been redesigned. The new design limits operation to a fixed slit width during any one flight, however slits with a range of widths are available.

The Ebert spectrometer is mounted so that the line of sight can be directed vertically downward through a clear arsenic trisulfide window located in the bottom skin of the aircraft or vertically upward to a rough-ground arsenic trisulfide diffuser plate located in the upper aircraft skin. When illuminated by sunlight the diffuser plate scatters solar radiation into the spectrometer optics. With the planar diffuser, solar spectra with 0.01 micron resolution have been recorded with the aircraft in level flight for scan angles 0 to 60^{o} from the zenith.

Two cameras are employed to photograph the clouds or terrain under observation. The first of these is a horizon-to-horizon tracker camera supplied with the aircraft and the second a small Siemens time lapse motion picture camera with 60^{o} field of view and line of sight vertically downward. The cameras can either be triggered from the spectrometer scan drive or independently. A third camera mounted in the upper hatch cover periodically photographs an image showing sun-aircraft orientation, time, aircraft heading, and an event counter.

Electronic data channels are recorded on a CEC multichannel galvanometer recorder. The following signals are continuously recorded: spectral signal, spectral signal times 10, wavelength, detector bias, pitch, roll, yaw, potential gradient, spectrum number or tracker and Siemens camera frame number, and a pilot actuated event mark. By recording either spectrum number or camera frame numbers, full correlation between photographic records and CEC traces is insured.

IV. INSTRUMENT MODIFICATIONS

A number of instrument modifications were required to convert the cloud spectrometer system for the background clutter and solar absorption study. These modifications will be discussed in this section of the report.

A. SCAN RATES AND FIELD OF VIEW

Scan rates and field of view are calculated assuming an operational aircraft altitude of 65,000 ft and a ground velocity of 435 nmi/hr. The angular field of view is 0.015 radians azimuth and 0.045 radians elevation. The azimuthal width of the field of view for a 45^{o} nadir angle is 0.227 nautical miles and thus the minimum scan time is about 0.50 seconds.

The maximum scan rate of the spectrometer is 1 second for a full grating excursion of 15^{o}. With the 100 line/mm grating used in first order, an excursion of about 5-1/2^{o} or a time of about 1/3 second is required to cover the 1.25-2.95 micron region. The effective scan time must be increased, however, since in order to cover the entire region two sets of grating isolation filters, one covering 1.25-1.95 microns and the second 1.65-2.95 microns, must be used. Since the switching time for the filter wheel is an appreciable fraction of a second, a decision was made to treat the 1.25-1.95 and 1.65-2.95 regions independently. The field of view of the spectrometer is determined by the slit dimensions. A new set of fixed slits 6 mm in length and 2 mm in width have been fabricated to give the required 3:1 field of view and 0.10 micron resolution.

B. SIGNAL-TO-NOISE REQUIREMENTS

A cooled PbS detector has been purchased and tested with the instrument. Figure 1 is a typical radiance spectrum for the 2.3-3.7 micron region recorded with scan time of 60 seconds and 0.5 cps electrical bandwidth. The signal-to-noise ratio is such that radiance levels of 10^{-5} watts/cm^2 sterod micron can be detected with signal-to-noise ratio considerably better than 2/1 for a 50 cps bandwidth and 0.5 second scan.

C. OPTICS

In order to permit 45^{o} and 80^{o} nadir measurements, an adjustable plane mirror is being mounted below the infrared window in the lower skin of the aircraft. The plane mirror can be rotated about an axis parallel to the

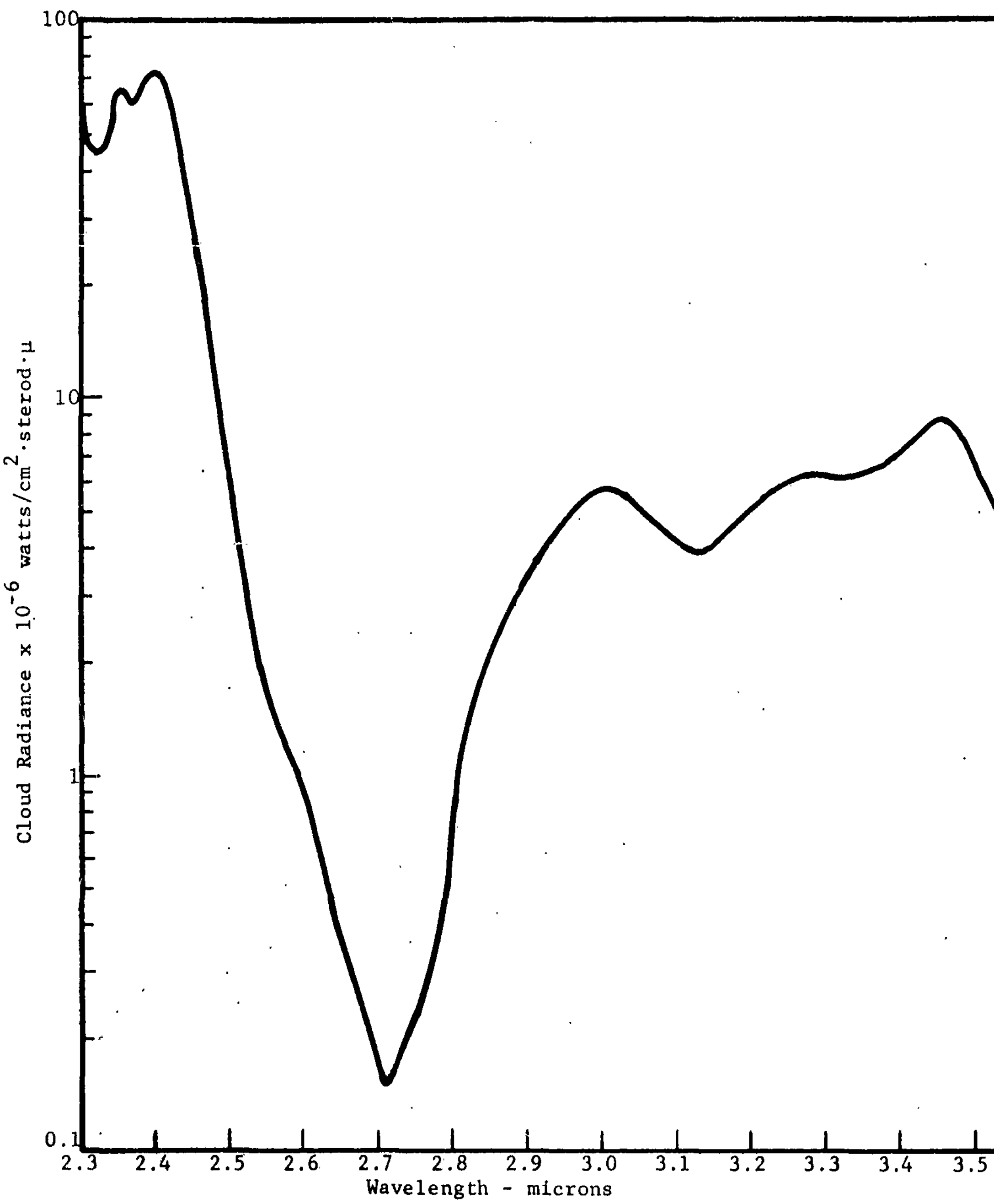

Figure 1: STRATUS DECK 35,000 ft
Aircraft altitude 37,000 ft
Electrical bandwidth = 0.5 cps
Spectral resolution = 0.05 μ
RMS noise 0.075 $\frac{\mu \text{ watts}}{cm^2 \cdot \text{sterod} \cdot \mu}$

direction of flight and can be set at any desired angle from 45-80°. Because of the large size of this mirror, rather elaborate protective cowlings are being manufactured by Lockheed Aircraft Corporation and will be mounted fore and aft of the mirror.

Solar spectra are being recorded by using a solar diffuser located in the upper skin of the aircraft. The diffuser is essentially a rough-ground infrared window which diffusely scatters solar radiation into the spectrometer optics, thus obviating need for a sun tracker. The planar configuration has given good results for angles of incidence from the zenith to about 60° from the zenith. In order to extend our measurements to 80° from the zenith, the planar diffuser will be replaced by a rough-ground hemispherical diffuser made of arsenic trisulfide glass. This approach was chosen rather than relocating the planar diffuser in the upper hatch cover in order to minimize the time and funds required for aircraft and optical modification.

D. TIME LAPSE CAMERA

Originally we had intended to mount a plane mirror below the down view camera window to obtain photographs corresponding to 45° and 80° nadir angles. It has proved simpler and less expensive to mount a second camera so that it views clouds and terrain over the same optical path used by the spectrometer. This was accomplished by mounting a small fold-over flat to the front center of the spectrometer telescope spider. Since this camera will "look" through an arsenic trisulfide window, black and white film will be used.

E. FM TAPE RECORDER

An Ampex AR-200 tape recorder has been obtained on a GF basis. Provision is being made to permit interchangeable use of this instrument and the existing CEC galvanometer recorder with the cloud spectrometer.

The following data channels will be recorded on fm tape: spectral signal, spectral signal times 10, wavelength, detector bias, pitch, roll, yaw, electric potential gradient.

The recording modes have been selected so as to permit analog-to-digital conversion using existing facilities.

V. MEASUREMENT PROCEDURE AND SCHEDULE

A. MEASUREMENT PROCEDURE

1. Background Measurements

Background measurements shall be made with the aircraft at its maximum operations altitude. Measurements shall be made only when the cloud cover is at least 50% and with cloud tops extending up to 30,000 feet altitude or more.

The aircraft's flight path shall be in the shape of a hexagon with the spectrometer's line of sight directed towards the interior of the hexagon. Successive circuits about the hexagonal path shall, so far as possible, be centered about a "fixed" point in the background so as to tend to view the same background scene on each successive circuit. Each side of the hexagon shall be approximately 100 miles long. Each hexagon shall be oriented such that one side of the hexagon coincides with the north-south direction.

A typical background measurement sequence shall consist of three successive hexagonal circuits with the spectrometer's line of sight at a fixed viewing angle. Either the first leg of the first hexagon, or the last leg of the last hexagon shall be in the north-south direction and such that the background is viewed at the minimum scattering angle and with the sun approximately 10° above the horizon. Successive legs of the hexagonal flight path will naturally define a family of scattering angles. The passage of time during successive circuits will produce insolation angles ranging from 10° above the horizon to approximately 60° above the horizon. In this way the same background is sampled at a fixed viewing angle for a well-defined set of scattering and insolation angles.

One such measurement sequence shall be performed for a viewing angle of 80° and another sequence for a viewing angle of 45°.

2. Solar Spectra

Solar spectrum measurements need not be performed in time proximity with the background measurements.

A single solar spectrum measurement sequence shall consist of the following series of measurements made in the course of a single day. Beginning at an altitude of 30,000 feet, with no clouds between the sun and the observer, solar spectra shall be obtained at the rate of one per mile over a flight path of approximately fifty miles, and at successively higher altitudes in increments of 20,000 feet up to the maximum operational altitude of the aircraft. Solar spectra at each altitude shall be obtained for insolation angles of 10° above the horizon, 45°, and at the zenith.

B. SCHEDULE

Aircraft and instrument modifications are scheduled for completion in time to permit data gathering during the peak of thunderstorm activity which extends from about July well into October. Flights are planned from Patrick Air Force Base to take advantage of the favorable weather conditions in the Caribbean area.